Ordovician–Silurian junctions in the Girvan district, S.W. Scotland

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Synopsis

The Ordovician–Silurian boundary at Girvan is represented by a variety of unconformable contacts; the basal Silurian rocks both overstep and overlap the upper Ordovician strata south and southwestwards. The most complete section across the junction is in a regressive shelly facies located north of the Girvan valley in the Craighead inlier. The Hirnantian High Mains Formation contains a moderately diverse *Hirnantia* fauna within channel fill sandstones. The overlying basal Silurian unit, the middle Rhuddanian Mulloch Hill Conglomerate, was deposited in submarine canyons at a variety of depths and contains an entrained *Cryptothyrella* fauna. The continuing regression evident across the junction and the facies patterns in the lowermost Silurian are related to the local emergence of fault-bounded blocks.

Introduction

The Ordovician and Silurian rocks of the Girvan district, S.W. Scotland contain a wide variety of siliciclastic sediments, together with locally diverse shelly and graptolite faunas; deposition occurred in a proximal fore-arc environment (Bluck 1983). In contrast to the graptolite facies of the Ordovician–Silurian boundary sections in the shale inliers of the Southern Uplands, the most stratigraphically complete junction section at Girvan is in a shelly facies.

Lapworth's detailed study of the Girvan succession (1882) was largely confirmed by the similarly substantial researches of Peach & Horne (1899). But neither study was aware of the terminal Ordovician unit, the High Mains Formation; thus the marked contrast between the faunas of the Ladyburn Mudstones of the Upper Drummuck Group and those of the Mulloch Hill Group led Lapworth (1882: 622) to consider the apparent hiatus between the top of his Ardmillan Series and the base of his Newlands Series to represent 'the grandest palaeontological break in the entire Girvan succession'.

In a detailed appraisal of the Drummuck Group, Lamont (1935: 294) noted the presence of a hitherto unrecognized unit of buff-weathering sandstone overlying the Drummuck Group and containing a distinctive shelly fauna. He considered the unit, the High Mains Sandstone, to represent the base of the Mulloch Hill Group and moreover (Lamont 1935: 289) suggested a correlation with the lower Llandovery. From this unit he briefly described and figured specimens of his new genus *Hirnantia*, which he based on material of *Orthis sagittifera* M'Coy from both the High Mains Sandstone and the Hirnant beds of Bala, north Wales, and noted the presence of *Meristella* sp. (*Hindella crassa incipiens*). Subsequently, Lamont (1949) described the trilobite *Flexicalymene scotica* from the High Mains Sandstone and modified his views on the correlation of the unit to include the possibility of a Hirnantian age. Ingham & Wright (1970) subsequently emphasized the presence of key elements of the terminal Ordovician *Hirnantia* fauna and concluded a correlation with the Hirnantian Stage.

Harper (1979*b*) noted the presence of two distinct associations of the *Hirnantia* fauna within the High Mains Sandstone and suggested the inapplicability of the term 'community' to contain the marked diversity of associations within the *Hirnantia* fauna. The formation has been described and mapped in detail and bulk samples of the two shelly associations investigated (Harper 1981). The thirteen taxa of brachiopod are currently being described (Harper 1984 and in preparation), whilst Owen (1986) has completed a monographic study of the five taxa of trilobites.

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The junction sections

The basal Silurian strata both overstep and overlap the upper Ordovician rocks of the district south and southwestwards (Cocks & Toghill 1973). The most stratigraphically complete boundary section is thus north of the Girvan valley in the Craighead inlier (Fig. 1) whilst the largest hiatus is developed in the coastal exposures south of the Girvan Valley and southwest of the main outcrop (Fig. 2).

(i) *Craighead inlier.* The terminal Ordovician unit, the High Mains Formation, crops out in the vicinity of High Mains farmhouse (Fig. 1). The unit is poorly exposed, and the detailed outcrop pattern (Harper 1981) was investigated by trenching and mechanical digging. The formation contains two associations of the *Hirnantia* fauna and a Hirnantian age is indicated. The High Mains Formation is overlain by the Mulloch Hill Conglomerate (the Lady Burn Conglomerate of Cocks & Toghill, 1973) but although the junction is not exposed it is assumed to be fairly sharp with a slight angular discordance.

(ii) *Main Outcrop.* The main outcrop of Silurian rocks in the Girvan district extends from Saugh Hill approximately northeast to Straiton (Cocks & Toghill 1973: fig. 1). The presence of major bedding-parallel structures have locally tectonized the shale units and may be responsible for the variation of thicknesses, along strike, of several of the formations. The junction of the Silurian with the underlying Ordovician is exposed on the west bank of Penwhapple Burn (National Grid ref. NX 2327 9769) some 500 metres downstream from Penwhapple Bridge (Cocks & Toghill 1973: fig. 4). Here, the local base of the Silurian is represented by the Tralorg Formation. At the junction the succession is inverted; however, the Tralorg Formation appears to overlie conformably grey micaceous sandstones and shales of the Shalloch Formation; the junction is apparently tectonized as are the shales within the underlying Shalloch Formation. In an adjacent quarry, graptolites of the *anceps* Zone indicate a middle Ashgill age for this part of the Shalloch Formation. Both units dip steeply south.

(iii) *Coastal Exposures.* The two main coastal exposures of the Ordovician–Silurian junction clearly demonstrate the southward overstep and overlap of the basal Silurian units. At the northernmost of the two exposures, the Haven (Cocks & Toghill 1973: fig. 3), the Craigskelly Conglomerate overlies the Shalloch Formation unconformably. However, farther south on Woodland Point the Woodland Formation unconformably overlies lower horizons of the Shalloch Formation, although pockets of Craigskelly Conglomerate lie between the two.

Faunal and facies changes at the Ordovician–Silurian junction

As noted above, the most complete boundary section is near High Mains farmhouse in the central part of the Craighead inlier (Fig. 1). The highest Ordovician strata in the Girvan district, in ascending order the Shalloch Formation, the Drummuck Group and the High Mains Formation, are sporadically exposed and the latter two units are locally highly fossiliferous (Figs 3–22). Within the Drummuck Group a variety of shelly associations dominated by brachiopods have been noted (Harper 1979*b*), and are currently under detailed description, together with the continuing documentation of the brachiopod taxa (Harper 1984 and in preparation). The associations are thought to have inhabited a spectrum of environments upslope and adjacent to the proximal parts of a submarine fan system. The highest strata of the group, the upper Rawtheyan South Threave Formation (Harper 1982), contain highly fossiliferous sandstones (the Ladyburn Starfish Beds of the Farden Member) and probable mudflow units (the Cliff Member); nevertheless background sedimentation is represented by bedded green mudstones and occasional siltstones containing low diversity faunas of minute inarticulate, enteletacean and plectambonitacean brachiopods. The boundary with the overlying Hirnantian High Mains Formation, although not exposed, is assumed to be fairly sharp. The High Mains Formation consists of fine-medium and medium grained quartz sandstones. The beds are massive with an apparent lack of internal sedimentary structures; horizons of shelly debris

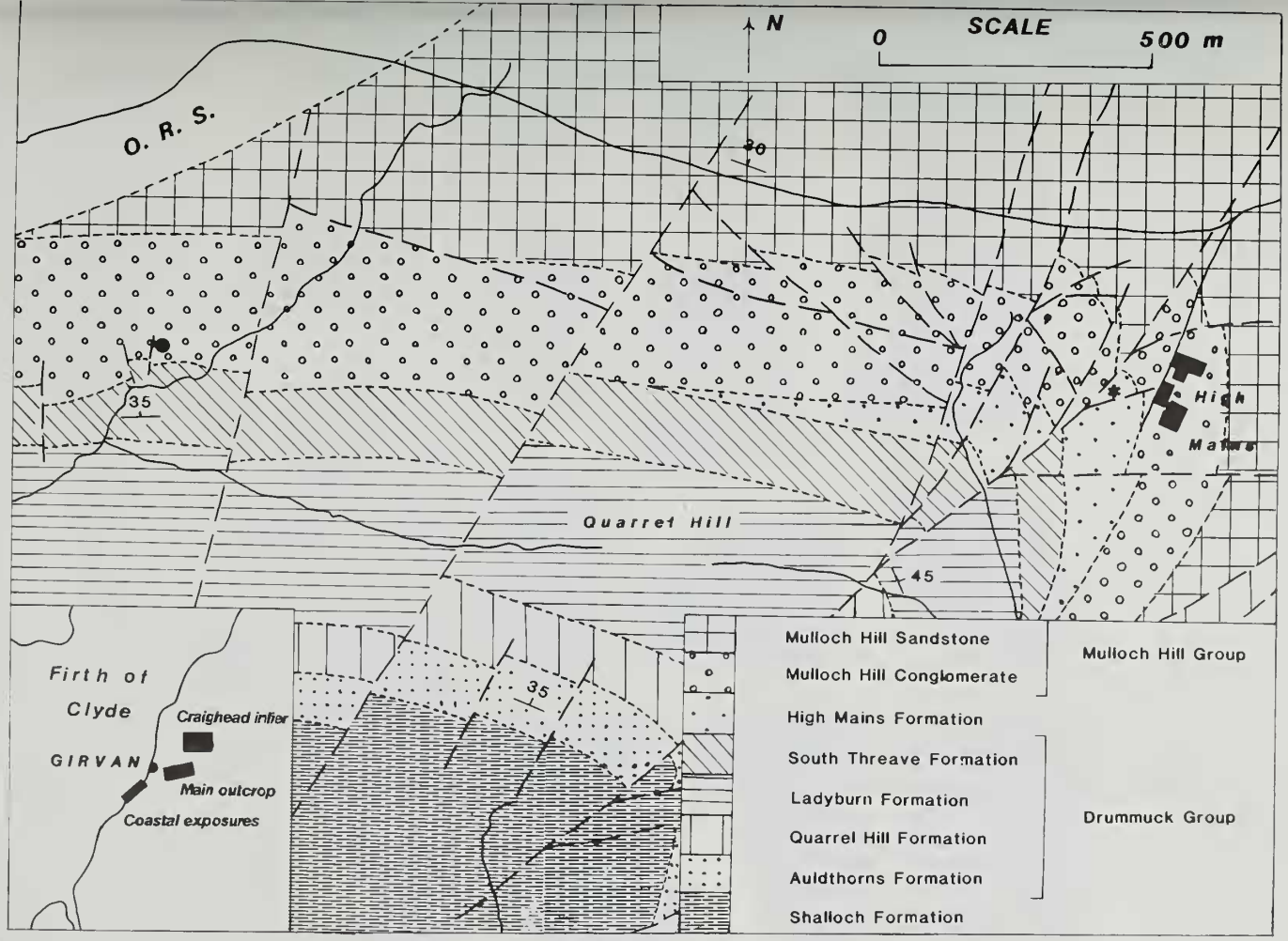


Fig. 1 Detailed map of the central part of the Craighead inlier; the black asterisk indicates the position of the High Mains trench (fossiliferous localities H1 and H2 of Harper 1981), whilst the black dot marks the site of a fossiliferous sandstone within the Mulloch Hill Conglomerate. The inset, bottom left, shows the approximate positions of three main areas of Silurian outcrop discussed.

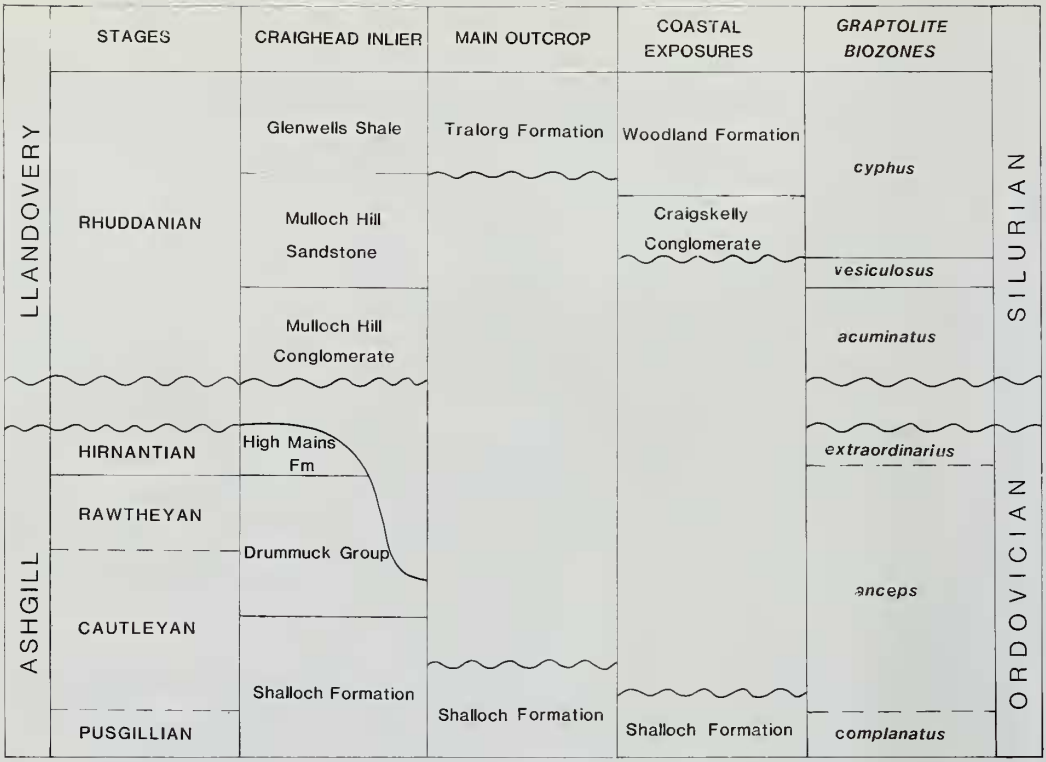
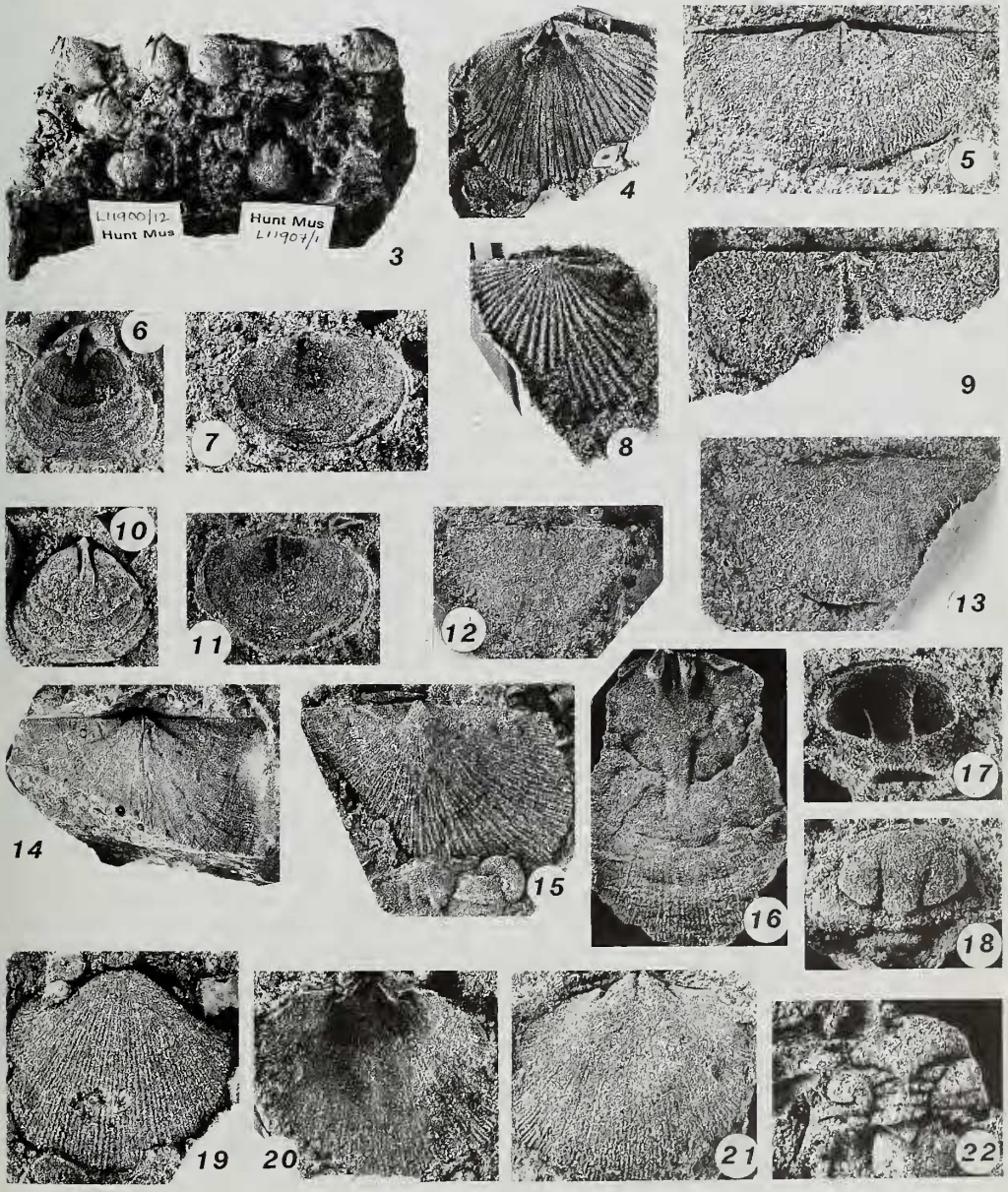


Fig. 2 Correlation of Ordovician–Silurian junction sections across the Girvan district with each other and the established shelly stages and graptolite biozones.

are developed at various levels in the formation. The lower 2 m of the formation exposed in the High Mains trench (Harper 1981: 250) comprises grey-green fine-medium grained, thinly bedded sandstones, whilst the upper 5·5 m is a hard medium-grained, thickly-bedded sandstone. Changes in grain size, bedding characteristics and faunal composition indicate a minor regression within the sequence. In view of the incomplete exposure and an apparent absence of

Figs 3–22 Brachiopods and trilobites from the High Mains Formation (Hirnantian), High Mains trench, Girvan. Repository: Hunterian Museum, Glasgow. Fig. 3, fossiliferous block of the High Mains sandstone dominated by internal moulds of both pedicle and brachial valves of *Hindella crassa* (J. de C. Sowerby) *incipiens* (Williams) and crinoid ossicles, × 1. Figs 4, 8, *Plaesiomys* aff. *porcata* (M'Coy). 4, HM L12238, latex cast of internal mould of brachial valve, × 2; 8, HM L12239, latex cast of external mould of pedicle valve, × 2. Figs 5, 9, 13, *Eochonetes* cf. *advena* Reed. 5, HM L12115, internal mould of pedicle valve, × 4; 9, HM L12117, latex cast of internal mould of brachial valve, × 4; 13, HM L12118, latex cast of external mould of pedicle valve, × 3. Figs 6, 7, 10, 11, *Hindella crassa* (J. de C. Sowerby) *incipiens* (Williams). 6, 10, HM L12242, latex cast and internal mould of pedicle valve, both × 2; 7, HM L12244a, external mould of brachial valve, × 3; 11, HM L12244b, latex cast of internal mould of brachial valve, × 3. Figs 12, 14–16, *Eostropheodonta* aff. *hirnantensis* (M'Coy). 12, HM L12105, latex cast of internal mould of brachial valve, × 2; 14, HM L12104, internal mould of pedicle valve, × 1; 15, HM L12103, latex cast of external mould of pedicle valve, × 2; 16, HM L12653, latex cast of internal mould of brachial valve, × 2. Figs 17, 18, *Hemiarges extremus* Owen, HM A16153, external mould and latex cast of cranidium, both × 2. Figs 19–21, *Hirnantia sagittifera* (M'Coy). 19, HM L12654, latex cast of brachial valve exterior, × 2; 20, 21, HM L1986, latex cast and internal mould of brachial valve, both × 2. Fig. 22, *Achatella* cf. *truncatocaudata* (Portlock), HM A16152, internal mould of cephalon, × 2.

sedimentary structures, palaeoenvironmental analysis of the High Mains Formation is equivocal. Nevertheless the thickness, geometry and lithology of the unit are compatible with deposition within channels which developed on the deeper parts of the shelf and the upper parts of the slope. Such environments (Dott & Bird 1979) may be characterized by apparently massive and structureless sandstones comprising channel fills in the order of 25 m thick. Elsewhere, various modes of channelling characterize predominantly argillaceous upper Ashgill sequences; these developed during the time of regression in response to the end Ordovician glacio-eustatic event (Brenchley & Newall 1980). At Girvan, however, a fall in sea level in excess of the 50–100 m estimated (Brenchley & Newall 1980: 34) is required and thus additional tectonic controls must be invoked.



To date, the High Mains Formation contains a fauna of thirteen brachiopod (Harper 1981) and five trilobite (Owen 1986) taxa. The brachiopods are characterized by a relative abundance of *Hirnantia sagittifera* (M'Coy), *Eostropheodonta* aff. *hirnantensis* (M'Coy) and *Hindella crassa* (J. de C. Sowerby) *incipiens* (Williams), important elements of the terminal Ordovician *Hirnantia* fauna, and less common *Glyptorthis*, *Plaesiomys*, *Platystrophia*, *Eochonetes*, *Eopholidostrophia*, *Fardenia*, *Rostricellula*, *Hypsiptycha* and *Eospirigerina* and an indeterminate enteletacean. With the exception of *Hypsiptycha*, all these forms have congeners in the underlying Drummuck Group. Moreover small individuals of *H. crassa incipiens* have been described previously from the Ladyburn Starfish Beds within the upper Rawtheyan South Threave Formation near the summit of the Drummuck Group (Reed 1917: 955; pl. 24, fig. 55) whilst Mitchell (1977: 54) has described and figured a species of *Hirnantia* from the Cautleyan Killey Bridge Formation, which is along strike in the Pomeroy inlier of the north of Ireland.

The Girvan fauna is quite distinct from other *Hirnantia* faunas (cf. Rong 1984*a*); whilst the fauna is dominated by key members of the *Hirnantia* fauna, it is of moderate diversity and supplemented by essentially relict North American forms. It is nevertheless different from other coeval assemblages, for example the *Holorhynchus* and Older Edgewood faunas (Rong 1984*b*: 117). Similarly, the trilobite fauna is dominated by North American relicts (Ingham *in* Harper 1981; Owen 1986).

The succeeding Mulloch Hill Conglomerate unconformably overlies the Drummuck Group. This formation is dominated by units of polymict, poorly sorted, of either clast- or matrix-supported conglomerate. The clasts range in diameter from a few centimeters up to 15 cm; a variety of lithologies is represented as is a range of shapes from near rounded to angular. The conglomerate units are separated by thinner beds of coarse impure quartz sandstone which are locally fossiliferous. Cocks & Toghill (1973) considered a shallow water environment of deposition likely for the unit whilst more recently Walton (1983: 133) indicated the sedimentology and fauna of the formation to be suggestive of shallow, shelf conditions. The available data however suggest an equally feasible alternative. The nature and thickness of the formation, in excess of 100 m, together with an ability to cut through some 350 m of strata over a distance of about five miles, suggest the Mulloch Hill Conglomerate was deposited in a channel across a gradient of depths. Clearly in the vicinity of Girvan the unconformity was not subaerial but rather resulted from downslope channelling during the earliest Silurian (see also Ingham 1978).

The fauna of the Mulloch Hill Conglomerate, although locally abundant within the sandstone units, is of low diversity. It is dominated by crinoid ossicles and the brachiopods *Cryptothyrella angustifrons* (Salter) and a species of *Rhynchotreta* (Cocks & Togill 1973). Both species have near identical relatives in the fauna of the upper Rawtheyan Ladyburn Starfish Beds (Harper 1979*a*). Such associations characterize shallow water environments created during the early Llandovery global transgression (Sheehan 1977).

Discussion

The faunal succession across the Ordovician–Silurian junctions indicates three phases of development: (a) above the Rawtheyan–Hirnantian transition a marked decrease in diversity concomitant with the development of a fauna comprising relict middle Ashgill elements of the North American province together with more abundant key taxa of the *Hirnantia* fauna, (b) during the early and middle Rhuddanian very low diversity faunas characteristic of the, then, recently colonized shallow water environments in the North American province, and (c) the arrival during the middle and late Rhuddanian of diverse, more typically Llandovery, shelly faunas. The former two events are accompanied by channel development during the regression whilst the latter is concomitant with net transgression. Similarly in the more complete and stable boundary section of the Oslo Basin relict Ordovician forms are not displaced by more typical Silurian elements until at least the middle Rhuddanian (Baarli & Harper 1986).

The mutual relationships of the basal Silurian facies and their southwestward overlap and overstep have been rationalized recently by Bluck (1983: fig. 6). Such features are considered to be the result of deposition on blocks of Ordovician strata separated by high-angle listric faults

with approximately east to west trends. Evidence of fault-controlled sedimentation has been documented within the middle Ordovician succession of the Girvan district in the classic study by Williams (1962), more recently refined by Ince (1984). Whilst the disposition and relative movement of such blocks can at least partly explain lower Silurian facies patterns in the Girvan district, a mechanism is available also to provide substantial and continued local regressions during the late Ordovician and early Silurian. The relative downfaulting of sequential blocks to the south, during extensional phases, may have resulted in the rotation of each block about an axis parallel to the trend of the listric faults; consequently the leading apex of each block may have become emergent. The overall effect locally is one of regression and channel development across relatively steep slopes. Both faunal and facies development thus occurred in a tectonically active environment at Girvan, against a background of global regression and transgression during the late Ashgill and early Llandovery respectively.

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